

RESEARCH HIGHLIGHTS: Perovskites

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Research on perovskites has progressed rapidly since the first perovskite-based solar cells with ~4% efficiency were reported in 2009. MRS Bulletin presents a selection of recent advances in this burgeoning field.

Many scientists believe that metal-halide perovskite solar cells will first see the light of day commercially in tandem form, stacked above silicon cells. This promises to boost commercial silicon module efficiency from about 20% to over 30%. But the necessary energy bandgap to realize such high-efficiency tandem cells has only been found in unstable perovskites.

Henry Snaith and his colleagues at the University of Oxford have concocted a light-stable perovskite with an ideal 1.74 eV bandgap for Si-perovskite tandem cells. The researchers substituted part of the formamidinium cations in formamidinium lead-halide perovskites with cesium.

Solar cells made from the new material, $[\text{HC}(\text{NH}_2)_2]_{0.83}\text{Cs}_{0.17}\text{Pb}(\text{I}_{0.6}\text{Br}_{0.4})_3$, have a power-conversion efficiency of

17% on their own. By combining the cells with 19% efficient silicon cells, the researchers were able to make tandem cells that are over 25% efficient. “With further improvements ... it is feasible that this system could deliver up to 30% efficiency,” the researchers said in their article published recently in *Science* (DOI: 10.1126/science.aad5845).

Researchers at the École Polytechnique Fédérale de Lausanne, led by Wolfgang Tress, have tailored a new perovskite composition to make solar cells with a record-breaking 20.8% power-conversion efficiency. They reported the findings in a recent issue of *Science Advances* (DOI: 10.1126/sciadv.1501170).

The researchers made the perovskite film in a single step from a solution of formamidinium iodide, lead iodide, methylammonium bromide, and lead bromide in a mixed solvent containing dimethyl formamide and dimethyl sulfoxide. The resulting mixed-cation, mixed-halide perovskite is rich in PbI_2 . The researchers reported that films with

excess PbI_2 show suppressed non-radiative recombination of electrons and holes, which decreases the solar cell efficiency. The external electroluminescence quantum efficiency, a marker of good cells, of the perovskite solar cell is reported to be at 0.5%, a number approaching the best silicon solar cells on the market.

Perovskites' promise for light-emitting devices (LEDs) has been hampered so far by low luminescent efficiency. Recently, researchers from Korea and the UK, led by Tae-Woo Lee of Pohang University of Science and Technology, reported perovskite LEDs with a current efficiency (at 42.9 cd/A) competitive to that of organic LEDs in *Science* (DOI: 10.1126/science.aad1818).

The team achieved the high efficiency by (1) spatially confining the excitons (electron-hole pair that result in light emission) in MAPbBr_3 nanograins

and (2) reducing the content of metallic lead atoms, which quench excitons in the film. To make the nanograin perovskite films, the researchers dripped chloroform onto the spinning MAPbBr_3 layer during spin coating. To reduce lead atoms, they used excess (2–7%) MABr in the perovskite solution.



Flexible perovskite light-emitting device. Credit: *Science*.

In solar cells, energy is lost due to the cooling of electrons (hot carriers) excited by supra-bandgap photons. The rate at which the hot carriers cool determines whether they can be used to boost the solar-cell efficiency or not. A few groups have used transient absorption (TA) spectroscopy to examine charge-carrier cooling properties of perovskites. In a recent *Nature Communications* article (DOI: 10.1038/ncomms9420), a team of researchers led by Felix Deschler at

the University of Cambridge observed a phonon bottleneck phenomenon. In this phenomenon, phonons (heat-carrying quasi-particles) that are formed while the charge carriers cool cannot decay quickly enough. Instead, they re-heat the charge carriers, slowing down their cooling rates.

Matthew Beard and his colleagues at the National Renewable Energy Laboratory also observed this bottleneck in lead iodide perovskites, suggesting

that the material could have a theoretical efficiency limit much higher than that of current solar-cell technologies. They found that the phonon bottleneck slowed down charge-carrier cooling by three to four orders of magnitude. So the carriers retain their initial energy for much longer periods of time. This extra energy could potentially be tapped in what is called a hot-carrier solar cell. The results were published recently in *Nature Photonics* (DOI: 10.1038/nphoton.2015.213).

In a promising advance for nanoscale optoelectronic devices, researchers made atomically thin two-dimensional (2D) sheets of organic–inorganic hybrid perovskites. The high-quality single-crystalline 2D (C₄H₉NH₃)₂PbBr₄ sheets,

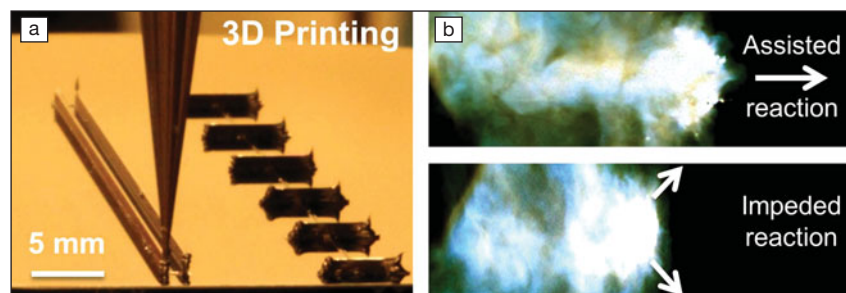
which the researchers grew directly from solution, had well-defined square shape and large size. The materials exhibited efficient photoluminescence, and the researchers were able to tune the emission color by changing sheet thickness

and material composition. Peidong Yang and his colleagues from the University of California–Berkeley, and ShanghaiTech University in China reported the advance in a recent issue of *Science* (DOI: 10.1126/science.aac7660).

3D printed architectures impart additional control over reactive materials

Reactive materials (RMs) are a class of composite materials that, when ignited, produce a sudden release of energy in the form of heat and pressure. Their performance, which can vary based on the choice of constituent materials, is typically midway between that of a propellant and an explosive. This makes them ideal for use in applications that rely on a quick, precise burst of energy such as ejector seats and airbags—situations where fractions of a second can make a world of difference. Recent advances in RM technology have largely focused on improving formulations, for example by altering the size, morphology, assembly, and ratios of the reactive particles. However, while effective in tailoring reactivity, many of these practices are limited by processing constraints or by diminishing returns in performance.

Christopher M. Spadaccini at Lawrence Livermore National Laboratory, Jennifer A. Lewis at Harvard University, and their colleagues have



(a) A three-dimensional printed channel (left) and hurdle (right) architectures composed of silver nanoparticle ink before deposition of the reactive material. (b) Snapshots of the propagating flame being assisted (top) or impeded (bottom) by the architecture. Credit: *Advanced Materials*.

introduced a method of tuning the reactivity of RMs through three-dimensional (3D) printed structures. Their work, published in a recent issue of *Advanced Materials* (DOI: 10.1002/adma.201504286), makes use of modern-day 3D printing techniques to create unique 3D RM architectures that offer an added degree of tunability in energy transport.

The researchers used Al/CuO (thermite) as the reactive material in this work. They evaluated two device architectures, “channels” and “hurdles,” which offer differences in the orientation of the product expansion relative to

the direction of intended propagation. First, a custom electrode is 3D-printed with a concentrated silver nanoparticle ink to define the architecture. A conformal film of Al/CuO nanoparticles is then deposited directly onto the printed electrodes through an electrophoretic deposition process.

The researchers studied the combustion process by monitoring the linear flame propagation velocity, a commonly used metric for comparing reactivity, using high-speed videography and varying device architectures, film thickness, and spacing between structures. They found that the orientation and spacing